




Inoculation theory in the post-truth era: Extant findings and new frontiers for contested science, misinformation, and conspiracy theories

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Abstract

Although there has been unprecedented attention to inoculation theory in recent years, the potential of this research has yet to be reached. Inoculation theory explains how immunity to counter-attitudinal messages is conferred by preemptively exposing people to weakened doses of challenging information. The theory has been applied in a number of contexts (e.g., politics, health) in its 50+ year history. Importantly, one of the newest contexts for inoculation theory is work in the area of contested science, misinformation, and conspiracy theories. Recent research has revealed that when a desirable position on a scientific issue (e.g., climate change) exists, conventional preemptive (prophylactic) inoculation can help to protect it from misinformation, and that even when people have undesirable positions, “therapeutic” inoculation messages can have positive effects. We call for further research to explain and predict the efficacy of inoculation theory in this new context to help inform better public understandings of issues such as climate change, genetically modified organisms, vaccine hesitancy, and other contested science beliefs such as conspiracy theories about COVID-19.

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1 | INTRODUCTION

Inoculation theory—the classic social psychological theory of resistance to persuasion that explains how an attitude or belief can be made resistant to attacks through pre-exposure to weakened forms of challenges (McGuire, 1970)—has established efficacy as a strategy to confer resistance against persuasion across issues and audiences (Banas & Rains, 2010), whether that influence comes in the form of political attack ads (Pfau et al., 2001), peer pressure to smoke cigarettes (Pfau et al., 1992), or rhetorical jabs made in political debates (An & Pau, 2004).

Much of the basic and applied work on inoculation theory has taken place in the contexts of politics (Compton & Ivanov, 2013) and health (Compton et al., 2016), but increasing attention is being paid to other contexts (for a comprehensive review, see Ivanov et al. [2020]), with contested and politicized science in general, and misinformation about science in particular, now seeing unprecedented attention (e.g., Cook et al., 2017; Lewandowsky & van der Linden, 2021; van der Linden, Leiserowitz, et al., 2017). Accordingly, this is an opportune time to engage in a critical review of inoculation theory research in these areas. The potential value of such work in the current “post-truth” era where misinformation abounds, scientific facts are increasingly called into question, and trust in science is being eroded is especially salient (Iyengar & Massey, 2018; Lewandowsky et al., 2017). By post-truth we mean “circumstances in which objective facts are less influential in shaping public opinion than appeals to emotion and personal belief” (McIntyre, 2018, p. 5). We contend that better communication—better writing, better speaking, better listening, better reading, better reporting, and throughout it all, better *thinking*—is critical in a time when “science is often perceived as just another opinion, rather than a foundation for discussion about policy options and practical solutions” (Menezes, 2018, p. 2).

Such a review can also help drive more scholarly attention to how persuasive arguments affect the public's knowledge of, and support for, policies (Nai et al., 2017) while also meeting calls for more attention to inoculation theory in understudied contexts (Compton, 2013). This review, then, has two main purposes: first, given recent concerns about a “post-truth” society (Lewandowsky et al., 2017), to consider what extant work on inoculation theory and contested science has revealed in contexts where “alternative facts” abound, and second, to propose new directions for inoculation theory research.

2 | INOCULATION THEORY IN THE CONTEXT OF POLITICIZED SCIENCE

Unfortunately, despite the efforts of many parties to communicate science effectively, using a vast array of communication channels and tools (Flemming et al., 2018), public misperceptions of science and scientific research continue (Dixon et al., 2015). Particularly in the face of scientific uncertainties, the new media environment, misinformation campaigns, and false-balance norms in journalism, the lines between myth and reality have become blurred, fueling a growing climate of confirmation bias and science denial (Iyengar & Massey, 2018; Lewandowsky & Oberauer, 2016). Scientists increasingly have their credibility, competency, and objectivity questioned (Hardy et al., 2019). Moreover, although scholars have attempted to debunk public misconceptions about topics such as climate change, genetically modified organisms (GMOs), and vaccine hesitancy, numerous studies have demonstrated the continued influence of misinformation: falsehoods are difficult to retract and correct once they have taken root in human memory (Gordon et al., 2017; Lewandowsky et al., 2012; Walter & Tukachinsky, 2019). Consequently, psychologists continue to grapple with the difficulties of correcting influential societal misconceptions.

What would be of great benefit, then, is a preemptive approach to avoiding such misconceptions. Fortunately, inoculation theory offers just such an approach—a way to proactively fight public misperceptions of science. Additionally, in situations when prevention is not possible, inoculation still seems to be promising then, too. For example, recent inoculation theory research has shown it to be an effective messaging strategy when used retroactively, as a therapeutic application of inoculation (Compton, 2020b)—boosting resistance to misperceptions

when they have already started to form (e.g., van der Linden, Maibach, et al., 2017). In this review, we focus on both prophylactic and therapeutic applications of inoculation theory to prevalent science misinformation across issues that are clearly consequential and harmful for both society and individuals, ranging from climate change to vaccinations.

2.1 | Inoculation: The grandparent theory of resistance to attitude change

Inoculation theory—"the grandparent theory of resistance to attitude change" (Eagly & Chaiken, 1993, p. 561)—is named and explained by a medical analogy: resistance to stronger challenges comes after pre-exposure to weaker challenges (Compton, 2013; McGuire, 1964). This is the basis for conventional vaccinations, like the annual flu shot. An annual flu shot is made with weakened versions of the anticipated most virulent strains of the upcoming flu season ("Key Facts about Seasonal Flu Vaccine," 2020). The flu is weakened to the degree that it is strong enough to motivate the body's immune system (e.g., the production of antibodies), but not so strong that it overwhelms. Such is the approach with persuasion inoculation. A persuasion inoculation is made with weakened versions of the anticipated persuasive challenges. These challenges are weakened to the degree that they are strong enough to motivate the mind's defense system (e.g., refutations of the counterarguments, like "mental antibodies") but not so strong that they overwhelm it (see McGuire, 1964).

Inoculation theory relies on two main mechanisms, namely (a) *forewarnings or threat* of a counter-attitudinal attack to motivate resistance and (b) a *preemptive refutation* of the attack to help model the counter-arguing process and provide people with specific content that they can use to refute future persuasive challenges (Banas & Rains, 2010; Compton, 2013). Since the earliest work of McGuire (1964, 1970), the prototypical inoculation treatment has therefore been a two-sided message—one that raises a few challenges against an existing desired position and refutes them (Compton, 2013). These messages are thought to do two main things: generate threat (or the realization that an existing, desirable position is at risk of being challenged) and motivate defensive protections, such as counterarguing against impending challenges. The presence of counter-attitudinal content is thought to trigger *threat* in message recipients but threat in inoculation is not so much fear as it is a motivation to protect a now-vulnerable (desired) position (Banas & Richards, 2017). Because threat is thought to be an important part of the resistance process (Compton, 2009; Compton & Pfau, 2005), inoculation messages often add additional features to elicit threat, including an explicit forewarning (Compton, 2013), as explicit forewarnings can boost threat (Compton & Ivanov, 2013). This finding is consistent with related research on resistance to persuasion which has found that making people aware of their own vulnerability to persuasive attacks generates resistance (Sagarin et al., 2002).

In addition to generating threat, the two-sided refutational message also provides content to be used in the counterarguing process for message recipients (Wyer, 1974). For example, the message provides information about possible impending persuasive challenges, and ways of refuting these challenges. This can be done passively by providing the refutations (passive defenses) or actively where the participant is asked to generate their own "antibodies" (active defenses). It is important to clarify, though, that remembering specific content from the treatment message is not necessary for resistance. Instead, findings from decades of inoculation scholarship show that inoculation can provide protection against counterarguments that were not even raised in the inoculation treatment message—a result described as the "umbrella" or "blanket of protection" (Banas & Rains, 2010; Parker et al., 2012; Pfau et al., 1997). Although the precise mechanisms (beyond memory) that help confer cross-protection, in particular, are not (yet) fully identified, threat and refutational preemption often work together to unleash a dynamic process that entails more talk and deeper thinking about the issue (e.g., Ivanov et al., 2012; Pfau et al., 2006). This process is particularly relevant in understanding why inoculation effects decay without regular "booster" shots as people might both forget and lose motivation to defend their beliefs over time (Maertens et al., 2020).

Lastly, extant reviews of inoculation theory scholarship, in general, have focused nearly exclusively on effects of inoculation messages on direct message recipients (see Compton & Ivanov, 2013; Compton, Jackson, & Dimmock, 2016; Ivanov, 2011; Lewandowsky & van der Linden, 2021). Although much of the focus in inoculation theory has been geared towards understanding the process of cognitive resistance, perhaps the greatest power of inoculation theory messaging lies in its ability to spread and diffuse over populations not initially exposed to the inoculation message (Compton & Pfau, 2009; van der Linden, Maibach, et al., 2017). Studies have demonstrated that inoculation treatments can enhance perceived interest in the target topic (Compton & Pfau, 2009) as well as the intent and likelihood to talk about societally contested issues (Lin & Pfau, 2007). This pass-along effect has been regarded as a particularly powerful means to sustain influence (Goldenberg et al., 2001) and has demonstrated to be equally effective as the treatment itself (Robinson & Levy, 1986; Southwell & Yzer, 2007). More recently, Ivanov and colleagues (2012) found that not only do those inoculated talk more about the issue, but also, the more they talk, the stronger their resistance. Other work has found that post-inoculation talk (PIT) contains both advocacy content and efforts to reassure (Ivanov et al., 2015). To return to the biological analogy: We might compare this social “spreading” of inoculation’s protection to herd immunity (van der Linden et al., 2018), or to how early biological vaccination material was literally passed along from community to community (Compton & Pfau, 2009).

2.2 | Inoculation theory and scientific misinformation: Existing research

The studies that have used inoculation to better understand how to generate resistance against scientific misinformation have yielded important discoveries. In this section, we look at extant research of inoculation theory in the context of controversial science issues.

2.2.1 | Climate change

No other issue has received more attention from an inoculation perspective than climate change beliefs and attitudes. And for good reason. Although 97% of climate scientists have concluded that humans are causing global warming (Cook et al., 2016), decades of concerted misinformation campaigns have attempted to mislead the public about the link between carbon dioxide emissions and climate change (Conway & Oreskes, 2010; Cook et al., 2018). Accordingly, research has explored whether public attitudes can be inoculated against such misleading persuasion attempts.

For example, in a national probability sample, van der Linden, Leiserowitz, et al. (2017) found that Americans were most familiar with—and persuaded by—a debunked online petition which claims that there is no scientific consensus on human-caused climate change. The so-called Global Warming Petition Project is one of the most potent online climate misinformation campaigns (van der Linden, Leiserowitz, et al., 2017). In fact, attacking the scientific consensus on anthropogenic climate change is the most popular topic in conservative op-eds about climate change (Elsasser & Dunlap, 2013) and the petition formed the basis of one of the most viral misinformation stories on social media in 2016, claiming that “tens of thousands of scientists have declared global warming a hoax” (Readfearn, 2016).

Van der Linden, Leiserowitz, et al. (2017) evaluated whether people can be inoculated against this specific petition. In their experiment ($N = 2167$), participants were randomly assigned to one of five conditions. Participants were either exposed to just the scientific consensus (the fact that 97% of climate scientists have concluded that human-caused global warming is happening), just the misinformation (a screenshot of the Global Warming Petition Project stating that over 31,000 scientists have signed a petition that there is no scientific evidence for human-caused global warming), a condition in which participants were first exposed to the scientific consensus before being exposed to the misinformation (false-balance) and two inoculation conditions. In the brief inoculation condition, participants were simply forewarned that politically motivated groups use misleading tactics to try to convince the public that there is a lot of disagreement between scientists, but that in fact, 97% of climate scientists

agree on the matter. In the detailed inoculation condition, the warning was followed by a more classic in-depth preemptive refutation (or *prebunk*) of the petition by highlighting that many of the signatories were fake (e.g., Spice Girls and Star Wars characters), that 31,000 only constitutes 0.3% of US science graduates, and that many of the signatories do not have expertise in climate science.

Results indicated that when participants were exposed to the full petition near the end of the survey, both inoculation conditions were effective in conferring resistance by protecting people's beliefs about the scientific consensus, including belief certainty. Although the misinformation by itself proved potent ($d = 0.48$)—decreasing people's judgments about scientific agreement in the absence of any inoculation—both the brief ($d = 0.33$) and detailed inoculation ($d = 0.75$) messages were effective in conferring resistance against such misleading tactics.

Two recent pre-registered replications of this study have been conducted further confirming that inoculation messages proved successful against the control and misinformation attack conditions, bolstering attitudes toward the scientific consensus on climate change (Maertens, Anseel, & van der Linden, 2020; Williams & Bond, 2020). Furthermore, Maertens et al. (2020) extended the original design by delaying the misinformation attack by one week finding that whereas the positive effect of a standard scientific consensus message decayed by about 50% over the period, the inoculation effect did not decay significantly. In general, the effect sizes were somewhat attenuated compared to the original study but that could be due to the fact that the replications used smaller and less diverse samples and so people's attitudes were generally more positive toward the scientific consensus (Maertens et al., 2020).

Cook et al. (2017) conducted a similar inoculation study using five groups and the same Global Warming Petition Project as the source of misinformation. Similar to van der Linden, Leiserowitz, et al. (2017), Cook et al. (2017) found that false-balance reduces perceptions of scientific agreement and that misinformation had a polarizing effect so that strong free-market supporters lowered their belief in global warming whereas low free-market supporters increased their acceptance of global warming. However, an important difference is that Cook et al.'s (2017) inoculation procedure involved explaining the flawed argumentation technique (i.e., the promotion of fake experts) that underlies the misinformation without mentioning the Global Warming Petition Project. A more typical inoculation approach is *fact-based*—counterarguments are paired with specific facts that challenge the counterargument. However, in Cook et al.'s (2017) study, rather than countering misinformation preemptively with facts, the inoculation was *logic-based*—where broader reasoning errors were paired with misleading denialist claims to expose the overarching flaws in reasoning (e.g., the use of fake experts or cherry-picking data, see Cook et al., 2018). Logic or technique-based inoculations have been an important advance as they avoid the need to raise and refute specific myths one at a time (Banas & Miller, 2013; Cook et al., 2017; Roozenbeek & van der Linden, 2019). Importantly, Cook et al. (2017) found that their inoculation messages were also able to neutralize the polarizing effect of misinformation about the scientific consensus. Cook et al. (2017) hypothesized that inoculation messages likely help shift people's attention from a more heuristic to reflective mode of information processing, aiding in the strategic monitoring of deception attempts.

Another recent study tested inoculation against a different example of climate misinformation: the argument that CO₂ emissions are good because CO₂ was plant food (Vraga et al., 2020). In a 2 × 2 design, the experiment also tested logic-based versus fact-based corrections. The authors found that logic-based corrections outperformed fact-based corrections, as they were effective in reducing misperceptions regardless of order.

2.2.2 | Anti-vaccination beliefs

The development of vaccines is one of the most crucial advancements in modern medicine (see Morgan & Poland, 2011). Yet, an increase in vaccine hesitancy across particularly Western nations is evident (Gallup, 2019). Despite the lack of a clear overview identifying all relevant factors of vaccine hesitancy (Larson et al., 2014), research suggests that erroneous beliefs and misconceptions about the underlying science play a substantial role in attitudes

towards vaccines (Salvador Casara et al., 2019). These false assumptions range from beliefs that the influenza vaccine actually causes the flu to claims of a debunked link between vaccines and autism. Though multiple large-scale studies have shown that there is no relation between the MMR vaccine and autism (e.g., Hviid et al., 2019), society still experiences the noxious effects of such misinformation today, including on COVID-19 (van der Linden et al., 2021).

Research shows that exposure to such myths and anti-vaccine conspiracies can fuel vaccine hesitancy and harm intentions to vaccinate (Dixon & Clarke, 2013; Jolley & Douglas, 2014). In fact, the spread of “weaponized” misinformation and conspiratorial arguments around vaccines play a critical role in shaping health-related behaviors (Broniatowski et al., 2018; Kata, 2012). Within the context of the COVID-19 pandemic, scholars have pointed out striking parallels between virology and the virality of the misinformation around it (Depoux et al., 2020). Indeed, commentators have argued that: “Misinformation on the coronavirus might be the most contagious thing about it” (Kucharski, 2020, headline).

To what extent can inoculation theory immunize citizens against vaccine misinformation? Wong (2016) and Wong and Harrison (2014) extended inoculation theory messaging into the area of vaccination beliefs. A three-phased study examined whether young women who had positive pre-existing attitudes towards the human papillomavirus (HPV) vaccine but had not yet completed any of the three doses of the vaccination could be inoculated against counterattitudinal attack messages questioning the safety and efficacy of the HPV vaccine and vaccines more generally. Specifically, participants in the treatment condition were exposed to a threat manipulation followed by inoculation messages (general, specific). After a 7-day delay, participants were exposed to attack messages concerning the safety and efficacy of the vaccination and completed a set of post-test measurements. Overall, results demonstrated that inoculated individuals held significantly more positive attitudes towards the HPV vaccination ($\eta^2 = 0.14$) than the control condition. Furthermore, the results also suggested that inoculation messages aimed at protecting general attitudes towards vaccines were as effective as HPV specific treatment messages. By demonstrating that a more general inoculation pretreatment on vaccines can afford protection against multiple counterattitudinal attacks related to the safety and efficacy of the HPV vaccine, results support the notion that one inoculation message might carry the potential to protect related but untreated attitudes in the same manner as vaccines may protect against a range of other viruses (see section on blanket of protection).

In another study, Jolley and Douglas (2017) ran two experiments where British parents were randomly assigned to one of five combinations of arguments: (1) conspiracy arguments only, (2) anti-conspiracy arguments only, (3) arguments refuting anti-vaccine conspiracy theories followed by arguments in favor, (4) arguments in favor of conspiracy theories followed by arguments refuting them, or (5) a control condition. Subsequently, participants reported their perceived risk of vaccines and beliefs in anti-vaccine conspiracy theories before being asked to imagine a scenario where a doctor informs them on a fictitious disease that can lead to serious consequences, such as fever and vomiting. Participants were then asked to indicate their intention to get their fictional child vaccinated against this (made up) disease. Results demonstrated a significant difference in vaccination intentions across conditions ($\eta^2 = 0.05$). Furthermore, vaccination intentions only improved when participants were presented with anti-conspiracy arguments prior to being exposed to the conspiracy theories ($p = 0.003$) and not when presented afterwards ($p = 0.164$). These findings further support the applicability of inoculation theory to vaccine hesitancy in that they demonstrate the possibility to intervene against the effects of anti-vaccine conspiracy theories by presenting people with accurate scientific information *beforehand*.

2.2.3 | Other controversial and contested scientific issues

Inoculation research has increasingly been applied to other contemporary contested scientific issues. For example, Wood (2007) investigated whether inoculation messages maintain consumer confidence in agricultural biotechnology when exposed to activists' persuasive arguments on this issue. A three-phase study was conducted where the final sample ($N = 558$) consisted of participants with either supportive, neutral, or opposing attitudes

towards the target topic. In Phase 1, all consenting participants completed a pretest survey measuring their attitudes toward agricultural biotechnology as well as perceived threat to their beliefs. Subsequently, while participants in the control condition did not receive a message in phase 2, participants in the treatment condition received a prototypical inoculation message (Compton, 2013) which raised and refuted three arguments related to inadequate testing, potential health risks, and environmental risks. In phase 3, all participants were exposed to an attack message upon which they completed the posttest survey measuring perceived threat, attitudes toward agricultural biotechnology, and counterarguing output. Importantly, the results showed that inoculated participants demonstrated significantly more positive attitudes toward biotechnology following an attack message despite initially reporting positive ($\beta = 0.22, p < 0.01$), neutral ($\beta = 0.18, p < 0.01$), or opposing attitudes ($\beta = 0.19, p < 0.01$). A similar pattern was evident in threat levels, which all significantly increased amongst initially neutral ($\beta = 0.15, p < 0.05$) and opposed participants ($\beta = 0.21, p < 0.01$). Counterarguing output also increased marginally among initially supportive and neutral participants ($\beta = 0.06, p < 0.10$). These findings not only extend the application of inoculation messages to the realm of societally contested issues but also demonstrate that individuals with differing pre-existing views can be inoculated. Thus, the theoretical assumptions, as well as the boundary conditions of inoculation theory were challenged and indeed, Wood (2007) called for a “rethinking” of the analogy.

Another divisive issue concerns public attitudes toward experimentation on animals for research. Indeed, public opinion polls from Pew show that the American public is sharply divided on the issue (Strauss, 2018). Nabi (2003) examined the role of affect in inoculating attitudes towards medical experimentation of animals and whether differing combinations of emotionally evocative content can confer resistance to persuasion. A total of 127 participants who were supportive of animal testing were either assigned to the inoculative pretreatment condition or the control condition. In the inoculation condition, participants were exposed to one out of four emotionally evocative pretreatment visuals that ranged in their intensity (high vs. low affect). Subsequently, all participants were exposed to an attack video message arguing that animal testing is cruel, cold, and insensitive. All participants then completed a posttest questionnaire measuring their attitudes toward animal testing, threat to belief, negative emotional arousal, and credibility of the narrator. Results indicated that emotionally consistent messaging (e.g., high/low affect across pretreatment, counterargument, and refutation) conferred greater resistance to persuasive challenges ($M = 4.84, SD = 1.39$) than emotionally inconsistent messaging ($M = 4.50, SD = 1.38$) and the control group ($M = 4.45, SD = 1.48$) at $p \leq 0.05$. These findings suggest that an emotionally evocative pretreatment can offer resistance to both emotion-laden information as well as attitude change and therefore emphasizes the importance of emotion in the process of conferring resistance through inoculation as well as the possibility to inoculate people against highly emotional content itself.

3 | INOCULATION THEORY: NEW FRONTIERS

Extant empirical findings are promising, but further research is needed to tease out a more nuanced understanding of how inoculation can combat threats to scientific knowledge and understanding—including more research into climate change beliefs; the global challenge of vaccine hesitancy (especially in the context of COVID-19); and other areas. Accordingly, below we synthesize key insights from the body of research reviewed above and outline new theoretical frontiers for inoculation theory scholarship in the post-truth era.

3.1 | More about prophylactic versus therapeutic inoculation

The studies reviewed here that have shown that inoculation messages can have positive effects on audiences regardless of their prior attitudes are particularly encouraging, since in the context of contested science, people

often have strong differing attitudes toward an issue. But such applications of inoculation theory have also raised questions about whether these are still “true” inoculation effects as well as how to conceptualize the analogy in further inoculation theory development (Compton, 2020b). On one end of the spectrum, an argument can be made that inoculation messages in this context are simply two-sided persuasive messages leading to attitudinal change (Compton, 2020b; Ivanov, 2017; Wood, 2007). Yet, Compton (2013) views the biological analogy as instructive rather than restrictive. Administering an inoculation to those already “afflicted” need not be inconsistent with the medical analogy when we consider the idea of therapeutic vaccines. Therapeutic vaccines are designed to treat an existing illness and provide protection against future attacks (Nossal, 1999). That is, in contrast to the more conventional prophylactic inoculation that preemptively protects against harm, a therapeutic inoculation both cures an existing harm *and* protects against future harm. Inoculation—even in its original medical context—is not limited, then, to conventional, prophylactic applications; extending inoculation messages to audiences that hold differing perspectives holds tightly to the analogic of inoculation theory (Compton, 2020b). Just as the incubation period of viruses can differ widely, so too can the incubation period of misinformation vary before it has fully persuaded an individual. In many of those cases, therapeutic approaches seem to have retroactive benefits. In fact, not only do inoculation messages seem to “work” with those with different positions on an issue, but such therapeutic applications also seem to avoid some of the pitfalls of other persuasive techniques. For example, although it is possible that administering a “vaccine” can cause psychological reactance in domains where beliefs are infused with ideology, consistent with Wood (2007), van der Linden, Maibach, et al. (2017), Williams and Bond (2020), and Maertens et al. (2020), all found no backfire effect and a near-identical positive inoculation pattern across prior attitudes and political ideology, where respondents of all stripes moved in directions consistent with the conclusions of climate science. Similar findings have been reported by others across domains, including climate change (Cook et al., 2017; van der Linden, Leiserowitz, 2017), emerging energy technologies (Bolsen & Druckman, 2015), and conspiracy theories about 9/11 and vaccine safety (Banas & Miller, 2013; Jolley & Douglas, 2017). Thus, one novel insight derived from this review is that unlike other forms of scientific messaging (e.g., persuasive frames about the impacts of climate change, see Hart & Nisbet, 2012), inoculation does not seem to elicit boomerang effects (or psychological reactance) in the context of contested scientific issues. One potential explanation for this observation is that inoculation often involves making people aware of their own vulnerabilities to attack and revealing the manipulation attempts of the persuader which may elicit enhanced deception monitoring (Cook et al., 2017; Maertens et al., 2020; Sagarin et al., 2002). Future research should continue to check for boomerang effects, and at the same time, add precision to our understanding of why inoculation messages seem more immune to backfire effects than other persuasion techniques.

3.2 | Source credibility: Who is delivering or administering the inoculation?

Source credibility has been extensively studied in persuasion research and is regarded as a key factor in the inoculation process (Ivanov, 2017). It can be understood as the perceived accuracy, validity, and plausibility of a message (Rice & Atkins, 2012). Source credibility also shares a complex link with related factors such as trustworthiness and perceived competence of the source (Metzger et al., 2003; O’Keefe, 2002). Although research continues to demonstrate the interplay between persuasion and source credibility (Wasike, 2017), studies examining its role in attitudinal resistance have been limited. Initial research found that persuasive attacks from credible sources reduce belief levels significantly (Tannenbaum et al., 1966). In general, though, the more positive perceptions a recipient has of the source of the inoculation, the more effective the inoculation process (An & Pfau, 2004; Compton, 2020a). Inoculation has also been used as a vehicle in itself to protect source credibility, for example, when it comes to the character of a political candidate (Pfau & Ken-ski, 1990). Interestingly, other findings suggest that when ethical concerns are raised in a scientist’s blog, the

scientist's trustworthiness is enhanced, and this is especially true when the scientist is the one to bring up the ethical concerns and not someone else. Scholars have referred to this process as "stealing thunder"—a related method within persuasion research where information likely to be revealed by an opposing party is preemptively exposed to downplay the significance and reduce its potential impact (Dolnik et al., 2003). Some scholars have extended the concept of source derogation to the biological analogy—albeit loosely—positing that the status of the "inoculator" (i.e. the source who delivers the "vaccine") could affect inoculation messaging (Anderson, 1967; Compton, 2013).

More research is needed to disentangle message from source effects, specifically in the context of contested science, for example, whether the voice of a single scientist or describing the consensus among a group of scientists is more persuasive in conferring resistance against attacks on the scientific consensus (van der Linden, Leiserowitz, et al., 2017). Similarly, not much is known about the role of the government and other organizations (e.g., the CDC) as a source in delivering inoculations against, for example, crises, fake news, and misinformation (Ivanov et al., 2016; van der Linden et al., 2018), especially as a function of other potential moderators, such as ideological worldviews (Oberauer & Lewandowsky, 2016).

3.3 | Active versus passive inoculation: learning by doing

The majority of inoculation research has relied on so-called "passive refutations" in which both the counter-arguments as well as the refutations are provided for the recipient—usually in the form of a conventional persuasive article (Lewandowsky & van der Linden, 2021). McGuire argued, however, that when participants are required to actively generate pro-and counter-arguments themselves, this would elicit a more involved cognitive process leading to enhanced resistance (McGuire & Papageorgis, 1961). Whether active inoculation generates greater resistance has remained an open empirical question (Banas & Rains, 2010) and inoculation research has only recently begun to fully examine the potential of active inoculation.

For example, one novel approach to active inoculation is pioneered by Roozenbeek and van der Linden (2018, 2019)—who designed an interactive choice-based fake news game (*Bad News*) during which participants actively generate their own antibodies by designing misleading content themselves in a controlled and simulated social media environment. During the approximately 15 min of gameplay, players are encouraged to walk a mile in the shoes of a fake news tycoon and are preemptively exposed to weakened doses of six common manipulation techniques used in the production of fake news: impersonation, polarization, emotion, discrediting, trolling, and conspiracy theories. The game itself warns players of the threat of fake news by challenging their beliefs as well as through impending attacks from other users. Participants were tested before and after gameplay using a series of real and fake news headlines. Results from a large-scale within-subject design ($N = 15,000$) finds that the active experience significantly inoculates ($d = 0.16$ to $d = 0.52$) players against misinformation (Roozenbeek & van der Linden, 2018, 2019) and that the game also boosts confidence, a critical factor in resisting persuasion (Basol et al., 2020). Subsequent research has replicated these results (Maertens et al., 2020), established the efficacy of the gamified inoculation approach in different (cultural) contexts (Basol et al., 2021; Roozenbeek et al., 2020), and found that the inoculation effects can last up to 2 months with regular re-testing, functioning much like "booster shots" help to extend the protection of medical inoculations (Maertens, Roozenbeek, et al., 2020). Yet, the comparative advantage over traditional "passive" inoculation pretreatments still remains unclear and so future research should evaluate gamified (active) versus traditional inoculation interventions (e.g., see Basol et al., 2021). The active inoculation approach developed by Roozenbeek and van der Linden (2019) has also been adapted to inoculate players against the logical fallacies found in climate change misinformation in a smartphone game called "Cranky Uncle" based on a humorous book applying logic-based inoculation to climate misinformation (Cook, 2020).

3.4 | Spreading the vaccine: herd immunity and post-inoculation talk

While it is known that false information spreads and replicates faster than true information (Vosoughi et al., 2018), herd immunity and community resistance can be achieved when the spread of the inoculation outpaces the online spread of inaccurate (scientific) information (Tambuscio et al., 2015). Considering that PIT demonstrated a positive impact on sharing issue-relevant information beyond the treatment material at the time of its 'injection' (Dillingham & Ivanov, 2016), PIT is regarded as a dynamic process which can play a crucial role in the momentum of social influence campaigns (Southwell & Yzer, 2007). In short, the spread of inoculation adds an important social dimension to the theory (Basol et al., 2021).

The context of contested science seems particularly well suited for further exploration of PIT. Consider, for example, Goldberg and colleagues' (2019) findings that talking about climate change with family and friends—having "climate conversations"—leads to more acceptance of climate science, including supporting key understandings, like the scientific consensus on climate change. Because inoculation theory leads to more talk, and more talk can lead to more acceptance of science, inoculation theory-based messages about science could be particularly powerful, and future research should focus on the best way to design such inoculation messages.

4 | CONCLUSIONS AND RECOMMENDATIONS

There is a substantial enough body of work of inoculation theory in the context of contested science and misinformation to begin to see accumulating knowledge, as we have shown here. Extant work is encouraging and timely, with consequential scientific issues ripe for attention from an inoculation perspective. We end our review with four main recommendations to pursue such possibilities.

1. Prophylactic (conventional, preemptive) and therapeutic (retroactive) inoculation messaging should be designed and tested across a wide range of scientific issues, to protect desirable attitudes and beliefs (prophylactic) and to change undesirable attitudes and beliefs and then make the new attitudes and beliefs more resilient (therapeutic). We urge scholars to identify inoculation messaging as such (prophylactic or therapeutic). The type of inoculation matters little in practice—inoculation messages in the field will be received by those with and those without the intended attitude already in place (see Basol et al., 2020; Ivanov et al., 2017). The type of inoculation does, though, matter when clarifying and developing theory (Compton, 2020b).
2. We have argued here that source credibility issues are particularly important in applying inoculation theory to scientific issues, especially when argumentation focuses on scientific consensus and channels of scientific information messaging (e.g., conventional news, government reports). Such efforts could also build on the theoretical work that explores issues of inoculation theory and character assassination—particularly pointed attacks on perceptions of a source's competence, character, or other image variables (Compton, 2020a).
3. Researchers exploring issues of inoculation theory should return to something explored in McGuire's earliest work—active and passive defenses (see McGuire & Papageorgis, 1961)—building off the extant work of Roozenbeek and van der Linden (2018, 2019, 2020) and the success they found with defenses built through active participation in video games that simulate persuasive arguments on social media.
4. PIT warrants continued study in the context of politicized science. Little is known about PIT in general, and with science communication applications in particular, regarding mapping the spread of talk (e.g., social network topologies) and some of the metacommunication dimensions of PIT. Consider, for example, that Cook et al. (2017) found inoculation effects through helping message recipients identify reasoning fallacies. Would this message content also spread through talk, and if so, could enhanced critical thinking also spread, both online and offline?

Of course, there is much to be learned about issues that have already received some attention in inoculation theory research—issues like climate change and vaccination beliefs—and research on these issues should continue. At the same time, there are a number of other topics that remain unexplored in inoculation theory scholarship, including GMO labeling, nanotechnology, and COVID-19. In fact, the onslaught of scientific misinformation about COVID-19, from fake cures (e.g., ingesting alcohol) to unfounded conspiracy theories about vaccines are ripe for inoculation theory scholarship (Basol et al., 2021; van der Linden, Dixon, et al., 2021).

In their classic review, Eagly and Chaiken (1993) noted that whilst the analogy is clever, many questions about inoculation theory remain unanswered. Amidst a worldwide “infodemic,” we contend that the study and application of inoculation theory has never been more relevant and exciting for social psychologists and communication scholars than it is today.

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